

## UNIT PRICE AND CHOICE IN A TOKEN-REINFORCEMENT CONTEXT

THERESA A. FOSTER AND TIMOTHY D. HACKENBERG

UNIVERSITY OF FLORIDA

Pigeons were exposed to multiple and concurrent second-order schedules of token reinforcement, with stimulus lights serving as token reinforcers. Tokens were produced and exchanged for food according to various fixed-ratio schedules, yielding equal and unequal unit prices (responses per unit food delivery). On one schedule (termed the *standard schedule*), the unit price was held constant across conditions. On a second schedule (the *alternative schedule*), the unit price was either the same or different from the standard. Under conditions with unequal unit prices, near-exclusive preference for the lower unit price was obtained. Under conditions with equal unit prices, the direction and degree of preference depended on ratio size (number of responses per exchange period). When this ratio differed, strong preferences for the smaller ratio were observed. When this ratio was equal, preferences were nearer indifference. Response rates on the multiple schedule were generally consistent with the preference data in showing sensitivity to ratio size. Results are discussed in terms of a unit-price model that includes handling and reinforcer immediacy as additional costs. On the whole, results show that preferences were determined primarily by delay to the exchange period.

*Key words:* choice, fixed-ratio schedules, second-order schedules, token reinforcement, unit price, key peck, pigeons

Individuals frequently must choose between outcomes that differ according to short- and long-term costs and benefits. Such decisions may relate to foraging for scarce resources, saving and spending money, or engaging in healthy and safe behaviors. For example, a consumer may decide whether to purchase a commodity at a particular store based on proximity, the quality and price of the commodity, or the availability of substitutable commodities at other locations. Similarly, an individual may decide whether to use an illicit substance based on perceived drug effects, the cost of the drug, or the availability of substitutable alternatives. Clearly, many behavioral decisions may be framed in economic terms and analyzed according to cost-benefit tradeoffs.

An interdisciplinary approach to behavioral decision making may be found in behavioral economics, a field that integrates concepts and principles from economic theories with research in experimental psychology. In recent years collaborative efforts of operant

psychologists and economists have resulted in the specification of economic concepts and methods for the experimental analysis of behavior (e.g., Bickel, Green, & Vuchinich, 1995; Green & Kagel, 1987; Hursh, 1980, 1984; Kagel, Battalio, & Green, 1995).

There has been much interest in the application of operant methods to economic concepts. One such concept is that of unit price, a cost-benefit ratio that subsumes cost factors (typically defined in terms of response requirements) and benefit factors (typically defined in terms of reinforcer magnitude) into a single metric. In its simplest form, unit price,  $P$ , can be defined as

$$P = \frac{FR}{A}, \quad (1)$$

where  $FR$  is a fixed response requirement, and  $A$  is reinforcer amount, or magnitude (Hursh, 1980; but see Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988, for an expanded definition). It follows from Equation 1 that unit price can be altered by (a) holding  $FR$  constant and varying  $A$ , (b) holding  $A$  constant and varying  $FR$ , and (c) varying both  $FR$  and  $A$  together. The same unit price may be arranged by varying  $FR$  and  $A$  together (i.e., in constant proportion).

Several studies have demonstrated the predictive value of unit price for describing changes in response output and total consumption under simple fixed-ratio (FR)

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Correspondence may be addressed to either author at the University of Florida, Department of Psychology, Gainesville, Florida 32611-2250 (e-mail: tafoster@ufl.edu or hack1@ufl.edu).

schedules of reinforcement (e.g., Bauman, 1991; Bickel, DeGrandpre, & Higgins, 1993, 1995; Bickel, DeGrandpre, Hughes, & Higgins, 1991; Collier, Johnson, Hill, & Kaufman, 1986; Foltin, 1991; Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988; Lea, 1978; Macenski & Meisch, 1998; Sumpter, Temple, & Foster, 1999; Tsunematsu, 2000; see DeGrandpre, Bickel, Hughes, Layng, & Badger, 1993, for a review). Some reports of equal consumption under conditions of equivalent unit price, but with different FR requirements and reinforcer magnitudes comprising that price, suggest the functional equivalence of these cost-benefit factors in determining consumption (Bickel, DeGrandpre, Higgins, & Hughes, 1990; Bickel et al., 1991; but see English, Rowlett, & Woolverton, 1995).

Madden, Bickel, and Jacobs (2000) extended the unit-price concept to choice between ratio schedules. Human cigarette smokers were given repeated choices between cigarette puffs available at equal and unequal unit prices. Unequal unit prices were arranged either by holding FR requirements constant while varying reinforcer magnitude, or by varying FR requirements while holding reinforcer magnitude constant. Equal unit prices were arranged by varying FR requirements and reinforcer magnitude in constant proportion such that both options yielded equivalent unit prices.

Madden et al. (2000) reasoned that when two schedules differ in unit price, the lower-priced alternative might not only generate greater response output, but also stronger preference. Consistent with this prediction, strong preference for the lower-priced option was found in all unequal unit-price conditions. These results are consistent with studies of concurrent ratio performance: exclusive preference for the smaller ratio with equal reinforcer magnitudes (Green, Rachlin, & Hanson, 1983; Herrnstein, 1958; Herrnstein & Loveland, 1975; MacDonall, 1988; Rider, 1979; Shapiro & Allison, 1978) and for the larger reinforcer magnitude with equal ratio values (Bickel & Madden, 1999; Carroll, 1987; Collier & Rega, 1971; Johanson & Schuster, 1974; Meisch & Lemaire, 1988; Neuringer, 1967).

A second prediction concerned conditions with equal unit price. From the findings of equivalent consumption under equivalent

unit price (Bickel et al., 1990; Bickel et al. 1991), Madden et al. (2000) reasoned that indifference should obtain when identical reinforcers are concurrently available at the same unit price, regardless of the cost-benefit components of the unit-price ratio. Inconsistent with this prediction, indifference was not obtained in the equal unit-price conditions: The cost and benefit components differentially affected preference. When the unit price of both options was relatively low, the schedule associated with the larger FR and larger reinforcer magnitude was preferred. At relatively high unit prices, the schedule associated with the smaller FR and smaller reinforcer magnitude was preferred.

Although inconsistent with a nominal application of Equation 1 to a choice context, the authors found that the results were well described by a modified version of the model that included separate terms for reinforcer delay and handling costs. According to this model, price is defined as

$$P = \frac{FR + H}{V}, \quad (2)$$

where  $FR$  is the response requirement,  $H$  is the cost accrued by handling the reinforcer, and  $V$  is the present value of the reinforcer. The  $V$  parameter was defined in relation to Mazur's (1987) hyperbolic discounting equation,

$$V = \frac{A}{1 + kD}, \quad (3)$$

where  $A$  is reinforcer amount and  $D$  is reinforcer delay. The parameter  $k$  measures the rate of delay discounting. Setting  $k = 1$ , Equation 2 simplifies to

$$P = \frac{(FR + H)(1 + D)}{A}. \quad (4)$$

This equation, which brings the unit price concept into better alignment with recent analyses of temporal discounting of reinforcer value (e.g., Mazur, 1987, 1997), provided a better description of the results of the equal unit-price conditions than did the nominal version of the model (Equation 1).

The present study sought to extend the generality of the Madden et al. (2000) results and of Equation 4 to pigeons and food reinforcers rather than humans and cigarette re-

inforcers. This permitted more direct comparisons to the research on concurrent-ratio performance, the majority of which has been conducted with nonhuman subjects and food reinforcers. Unlike prior work in this domain, the present study utilized schedules of token reinforcement. In this type of arrangement, responses produce tokens according to one schedule (token-production schedule) and opportunities to exchange those tokens for food according to a second schedule (exchange schedule). Token reinforcement schedules are useful for examining unit price because the delivery of a token signals the completion of a response requirement and thus the amount of and temporal distance to food. Token-production and exchange schedules can be systematically altered, both separately and together, to produce a variety of unit prices or the same unit price with different parameters.

In the token system used here, pecks on a side key illuminated stimulus lights that accumulated in the experimental space and became exchangeable for food by pecking the center key during distinct exchange periods (see Foster, Hackenberg, & Vaidya, 2001; Jackson & Hackenberg, 1996). Token-production and exchange schedules combined with reinforcer durations to produce a range of unit prices and unit price configurations. Unit price of one schedule (the standard) was held constant within a phase, whereas unit price of the other schedule (the alternative) was varied across conditions within a phase. In Experiment 1, pigeons chose between food reinforcers available at unequal unit prices. In a few conditions, contingencies arranged reinforcers at equal unit prices. In Experiment 2, reinforcers were always available at equal unit prices. In both experiments response requirement and reinforcer magnitude were varied by manipulating token-schedule parameters. Because of the often extreme preferences generated by concurrent-ratio schedules, choices were preceded each session by extended exposure to each of the component schedules (the components comprising the concurrent schedule in effect later that session) in a multiple schedule. Use of the multiple schedule not only ensured contact with the component schedules but also provided response rate data to relate to changes in unit price.

## EXPERIMENT 1

### METHOD

#### *Subjects*

Four White Carneau pigeons (*Columba livia*) served as subjects. Pigeons 756, 727, and 970 had a history of responding under token reinforcement procedures, and Pigeon 530 was experimentally naive. The pigeons were housed individually in a temperature- and humidity-controlled vivarium (lights on from 7:00 a.m. to 11:00 p.m.), where they had continuous access to water and grit. The pigeons were maintained at approximately 80% of their free-feeding weights.

#### *Apparatus*

One Lehigh Valley Electronics® operant chamber for pigeons, measuring 350 mm high, 350 mm wide, and 310 mm long, served as the experimental space. The modified control panel contained three Plexiglas response keys, each 25 mm in diameter. The keys were aligned horizontally 82 mm apart, center to center, and were located 240 mm from the floor. Each key required a force of approximately 0.23 N to operate. Each key could be transilluminated yellow, red, or green. A 7-W houselight, located 60 mm above the center response key, provided diffuse illumination. Primary reinforcement consisted of access to mixed grain delivered by a solenoid-operated food hopper. The hopper aperture, centrally located in the bottom third of the control panel (110 mm below the center key and 90 mm above the floor grating), contained a magazine light and a Med Associates® photocell apparatus. Interruption of the photobeam occurred upon entrance into the hopper aperture, which allowed precise timing of hopper access. Thirty evenly spaced, red light-emitting diodes (LEDs) served as tokens. Hereafter, the LEDs will be referred to as tokens. Tokens, arranged horizontally 12.7 mm apart and 40 mm above the response keys, protruded 3 mm into the chamber. Tokens were presented and withdrawn through operation of an electromechanical stepping switch (Lehigh Valley Electronics®, model 1427) mounted on the outside top of the chamber enclosure. Tokens were always presented from left to right and withdrawn from right to left. Token onset and offset were accompanied by auditory feedback from the

stepping switch. The chamber was housed within a ventilated, sound-attenuating shell. A white noise generator provided additional masking noise. Experimental contingencies were controlled by Med-PC® Version 2 software on an IBM® PC-compatible computer located in an adjacent room.

#### Procedure

*Token-production and exchange training.* Pigeons 756, 727, and 970 had extensive experience under token-reinforcement schedules, so preliminary training was unnecessary for them. Only Pigeon 530 was trained to produce and exchange tokens for food. The training procedure used has been described in detail elsewhere (Foster et al., 2001), so it will be described only briefly here. Following adaptation to the chamber (which included a session with all 30 tokens illuminated) and sessions during which the offset of illuminated tokens was paired with presentation of the grain hopper, Pigeon 530 was trained to peck the center (red) key to exchange illuminated tokens for grain by reinforcing successive approximations to pecking the center key. A single peck to the center (hereafter, exchange) key turned off a token and raised the grain hopper for 2 s. After the token-exchange response was established, responses to a side key were shaped using the illumination of a token as a consequence. Token illumination was accompanied by a .01 s flash of the house-light and keylight, and was followed immediately by an exchange period. The exchange period was signaled by illumination of the exchange key. (In later conditions in which multiple tokens accumulated prior to exchange, the exchange key remained illuminated until all tokens had been exchanged for food.) Initially, only one side-key response (hereafter, token-production response) was necessary to present the token and the exchange key. Across several sessions, the token-production response requirement was gradually increased to FR 50, and the side-key colors to be used during the experiment were presented. In the terminal performance, completing a FR 50 on the token-production key (lit green or yellow with  $p = .5$ ), illuminated a token and the exchange key, one peck on which raised the food hopper and turned off one token.

*Experimental procedure.* Second-order sched-

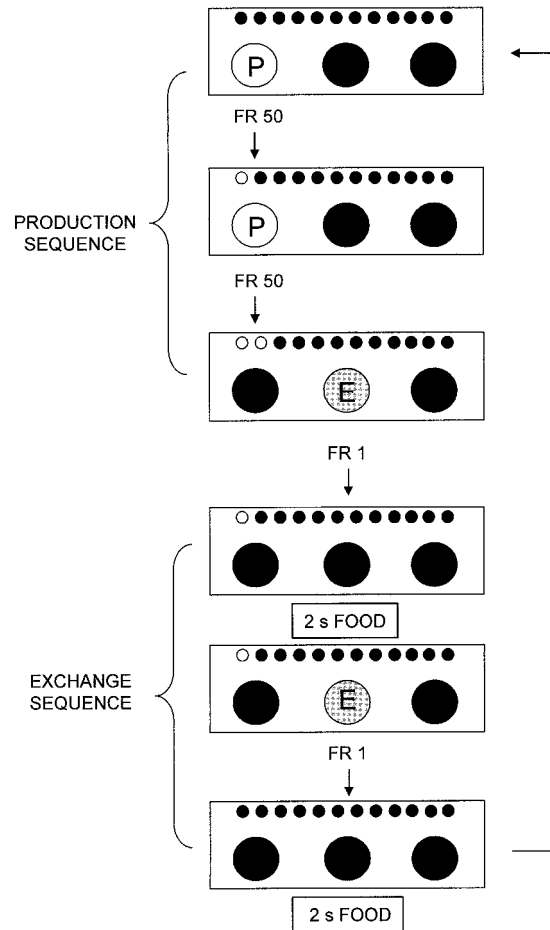


Fig. 1. Diagram of an FR 2 (FR 50) token reinforcement schedule. Each panel depicts a three-key intelligence panel with a row of 12 token stimuli (smaller circles above the keys). See the text for more information.

ules of token reinforcement arranged food presentation at various unit prices. Parameters of the token production and exchange schedules were varied along with reinforcer magnitude to produce a range of unit prices. Figure 1 shows a diagram of a second-order schedule of token reinforcement. In this diagram, the exchange schedule is FR 2, and the production schedule is FR 50. Hereafter, such exchange and production schedule combinations will be abbreviated FR 2 (FR 50). During the token-production sequence (top panels), tokens are presented according to a FR 50 schedule. Hence, each FR 50 completion produces one token. During the token-exchange sequence (bottom panels), an exchange period is presented according to an

Table 1

The sequence of conditions, number of sessions per condition, and mean number of total choices per session for the final five sessions of each condition (in parentheses) in Experiment 1.

Unit price <sup>a</sup>	Alternative schedules	Unit price	Pigeon			
			756	727	970	530
Phase 1: Standard schedule <sup>b</sup> FR 2 (FR 25) 2 s food, unit price 12.5						
U	FR 2 (FR 100) 1 s food	100	15 (19)	15 (19)	15 (19)	15 (19)
E	FR 2 (FR 25) 2 s food	12.5	17 (18)	15 (18)	15 (18)	15 (18)
U	FR 2 (FR 25) 4 s food <sup>c</sup>	6.25	15 (18)	19 (8.4)	32 (9.2)	15 (18)
U	FR 1 (FR 50) 1 s food	50	15 (20.2)	20 (20.4)	17 (20.8)	16 (21)
E	FR 4 (FR 50) 4 s food	12.5	15 (12)	15 (12)	17 (12)	15 (12)
U	FR 2 (FR 50) 2 s food	25	15 (18)	15 (18)	18 (18)	17 (18)
E	FR 2 (FR 25) 2 s food	12.5	15 (18)	23 (18)	17 (18)	24 (18)
TOKENS REMOVED						
E	FR 50; 4 s food	12.5	15 (18)	17 (18)	24 (18)	17 (18)
U	FR 50; 8 s food <sup>c,d</sup>	6.25	17 (18)	26 (9.6)	27 (8)	16 (18)
U	FR 100; 4 s food <sup>d</sup>	25	15 (18)	16 (18)	17 (18)	18 (18)
Phase 2: Standard schedule FR 2 (FR 50) 2 s food, unit price 25						
U	FR 2 (FR 100) 1 s food	100	19 (19.4)	17 (19.4)	15 (19)	15 (19)
U	FR 2 (FR 25) 4 s food	6.25	33 (8)	16 (8)	17 (8)	16 (8)
E	FR 2 (FR 100) 4 s food	25	15 (16)	22 (15.6)	17 (16)	23 (16)

<sup>a</sup> E = equal; U = unequal.

<sup>b</sup> In this notation, the token exchange schedule precedes the token production schedule.

<sup>c</sup> For Pigeons 756 and 530, the ALT schedule configuration was FR 1 (FR 25) 4 s food. In the tokens-removed condition, the ratio was FR 25.

<sup>d</sup> For Pigeons 727 and 970, these conditions were presented in reverse order.

FR 2 schedule. Thus, once two sets of FR 50 are completed and two tokens are delivered, the exchange period begins. During the exchange period, a single response on the exchange key extinguishes one token and delivers 2 s food. Once two exchanges occur (one per token earned), the production schedule begins again. Overall, the second-order schedule requires a total of 100 production responses for a total of 4 s food access, or a unit price of 25.

Choice between schedules arranging unequal and equal unit prices was examined using a Findley (1958) changeover-key procedure. Choice alternatives were presented on the same side key, and were correlated with distinct stimuli. When a choice option was presented, the center (blue) key was illuminated and pecks on this key switched the choice option presented. For example, one peck on the center (blue) key would switch the color presented on the side key from yellow to green; a second peck on the center key would switch the side-key color back to yellow. Hereafter the center (blue) key will be referred to as the changeover key. The center

key, when lit red, also served as the exchange key.

The experiment contained two phases within which several conditions were conducted. In a given condition, choice was between a *standard* (STD) schedule (which remained constant throughout a phase) and one of several *alternative* (ALT) schedules (which changed across conditions). A phase was defined by the unit price of the STD schedule, 12.5 in Phase 1 and 25 in Phase 2. Across conditions, pigeons chose between the STD schedule and ALT schedules that arranged unit prices ranging from 6.25 to 100. Some conditions within each phase arranged choice between equal unit prices, and some conditions in Phase 1 were replicated without tokens present. Under these latter conditions, although tokens were absent from both choice options, the exchange sequence remained in place (i.e., following ratio completions, pecking the exchange key produced food). Table 1 presents the sequence of conditions and the number of sessions per condition for each pigeon. Generally, conditions



were presented in the same order for each pigeon.

Because concurrent-ratio schedules generate strong preferences for the richer alternative, thereby limiting exposure to the leaner alternative, we arranged exposure to both schedules each session. This was accomplished by dividing the sessions into two parts. In the first part, a two-ply multiple schedule was arranged, in which two schedules were presented successively in the presence of distinct stimuli. Each component of the multiple schedule lasted for one schedule presentation, and each component was presented twice. To minimize strict alternation, the first and third component types were determined with  $p = .5$  and the second and fourth were complements of the first and third, respectively. Component presentations were separated by a 30-s blackout period during which all stimulus lights were extinguished and no contingencies were in effect.

In the second part of the session, the concurrent schedule (described above) was arranged, in which the two schedule components from the multiple schedule were simultaneously available. Thus the multiple schedule provided exposure to the two schedule components (STD and ALT) arranged in the concurrent schedule. The onset of the second (concurrent-schedule) part of the session was signaled by the illumination of the changeover key. A single peck on this key illuminated the side key (yellow or green) with  $p = .5$ . Thereafter the color of the side key depended on a pigeon's choices. Choice of a schedule was defined as completing the token production and exchange requirements for that schedule. Pecks on the changeover key prior to responding on a choice alternative changed the choice alternative presented. If a peck occurred on the changeover key after responding had begun on a choice alternative, response counters were set to zero and any tokens produced were withdrawn. Although the changeover key was occasionally pecked once a ratio was begun on one schedule, it was never pecked after a token was presented. Following a reinforcer on either schedule, choice contingencies were immediately reinstated with the schedule not selected on the previous cycle in place.

The green and yellow keylights correlated with the different choice alternatives were

counterbalanced across pigeons. For Pigeons 756 and 727, yellow was assigned to the STD schedule and green to the ALT schedules, with these assignments reversed for Pigeons 970 and 530. The location of the side key also varied across pigeons: left key for Pigeons 756, 727, and 970, and right key for Pigeon 530.

All sessions were preceded by a 5-min blackout period. According to conditions, tokens were exchangeable for varying food-access periods. Across conditions, sessions ended once pigeons received between 88 and 92 s of grain access (from multiple and concurrent segments combined). Thus session-wide consumption was held roughly constant. This amount of food was selected to minimize the need for postsession feeding. Only 1 of the 4 pigeons (530) occasionally required postsession feeding (about 4 g on average).

Sessions were conducted daily. Conditions were in effect for at least 15 sessions, after which stable performance was judged by visually inspecting the proportion of choices (i.e., exchange periods) allocated to the standard schedule in the last five sessions for any evidence of a monotonic trend or extreme variability. A measure of relative preference was used because the absolute number of exchange periods could vary across conditions (i.e., depending on the configuration of the ALT schedule). All analyses are based on the final five sessions of each condition.

## RESULTS AND DISCUSSION

Figure 2 shows relative preference for the STD schedule as a function of nominal unit price of the ALT schedule for all pigeons in Experiment 1. Absolute frequencies of exchange periods are shown in Table 1. Under unequal unit price conditions (black circles), choice proportions approximated 1.0 across all comparisons in which the nominal unit price of the STD schedule was lower than that of the ALT schedule. For the single condition in which the STD schedule arranged a higher nominal unit price (12.5) than did the ALT schedule (6.25), the proportion of STD choices approximated zero in all cases. Thus, under these unequal unit price conditions, all pigeons showed exclusive or near-exclusive preference for the lower-priced choice alternative. With one exception (Pigeon 727; unit price = 6.25), withdrawing token presenta-

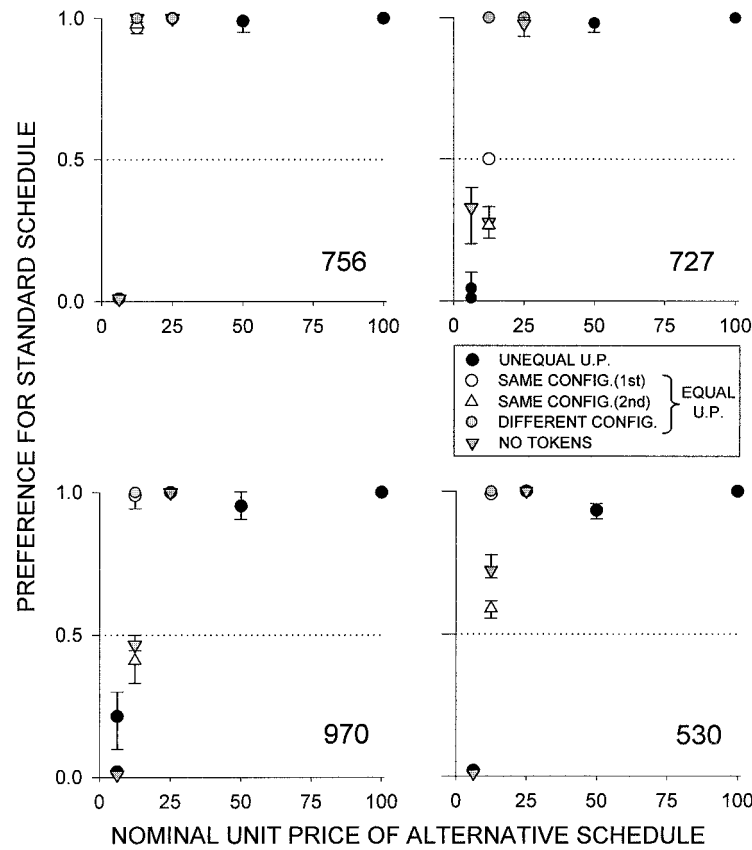


Fig. 2. Mean proportion of choices for the standard schedule across nominal unit prices of the alternative schedule. Data from unequal (black circles) and equal (open and gray circles) unit-price conditions are shown. Open circles depict original exposures to identical choice schedule configurations; open triangles show the replications. Gray circles depict data from different choice schedule configurations. Inverted gray triangles represent no-token conditions. Error bars indicate the range of values contributing to the condition mean. See Table 1 for condition-related details.

tions from the schedule arrangements did not appreciably alter choice proportions.

Under equal unit price conditions, preference was described less well by nominal unit price. In Phase 1, some STD and ALT schedules had equal unit prices (12.5). During the first exposure to identical schedule configurations (the FR 2 [FR 25] 2 s food condition; open circles), 3 of the 4 pigeons showed exclusive preference for the STD schedule, with 1 approximating indifference (727). Upon replication (open triangles), preference shifted from near exclusivity toward indifference in 2 pigeons (970 and 530). When choice was between equal unit prices arranged by different schedule configurations (gray circles), near-exclusive preference for the STD schedule (FR 2 [FR 25] 2 s food) was observed.

This schedule arranged a lower response requirement and smaller reinforcer magnitude than did the ALT schedule (FR 4 [FR 50] 4 s food). In Phase 2, equal unit prices again produced exclusive preference for the STD schedule, which arranged a smaller response requirement and smaller reinforcer magnitude than did the ALT schedule.

The strong preferences obtained under comparisons of nominally equal unit price suggest a role for the particular cost-benefit components of the unit-price ratio. We reanalyzed these data in relation to the modified unit-price model (Equation 4) that takes into account differences in cost-benefit components. To apply Equation 4 to the present data, we defined handling cost ( $H$ ) as the exchange-schedule requirement (one response

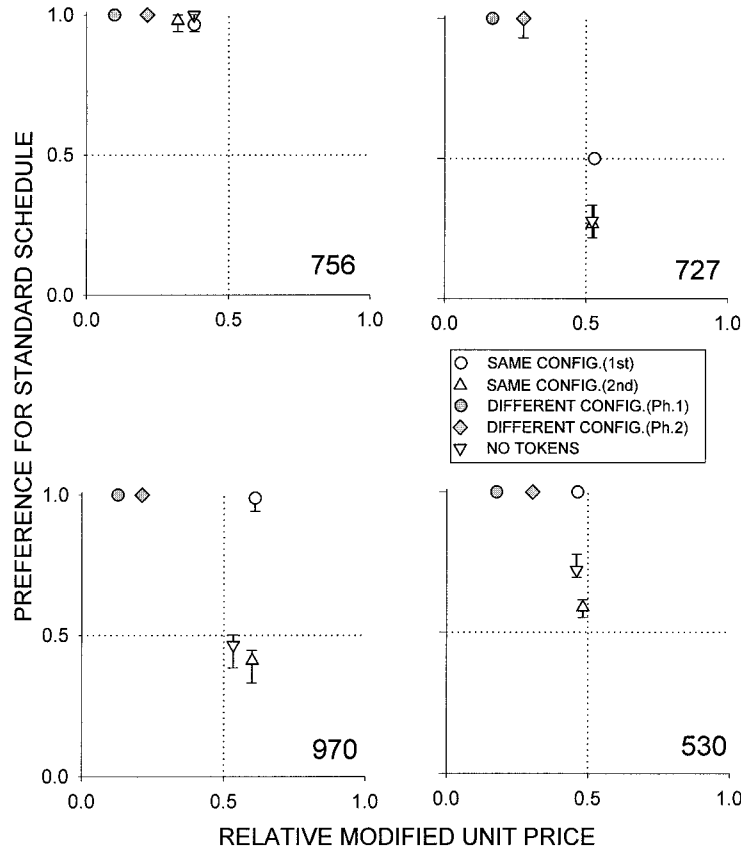


Fig. 3. Mean proportion of choices for the standard schedule as a function of relative modified unit price of the standard schedule (Equation 4). Data from equal unit-price conditions in Phases 1 and 2 are shown. Open symbols depict exposures to identical choice schedule configurations. Original exposures (circles), token replications (triangles), and no-token replications (inverted triangles) are shown. Gray symbols depict exposures to different choice schedule configurations (Phase 1, triangles; Phase 2, diamonds). Error bars indicate the range of values contributing to the condition mean. See Table 1 for condition-related details.

per reinforcer delivery), reinforcer amount ( $A$ ) as the aggregate food-access time summed across all reinforcers within an exchange cycle, and reinforcer delay ( $D$ ) as the mean obtained delay to the exchange period timed from the first key peck of a production cycle (i.e., the preratio pause was removed). In some conditions the less-preferred schedule was not selected in the final five sessions of a condition; therefore, for all conditions the delay values were obtained from responding in the multiple-schedule segments.

Figure 3 plots preference for the STD schedule under the equal unit-price conditions as a function of relative modified unit price of the STD schedule. Absolute values for exchange delay and modified unit price are shown in Appendix A. In Phase 1, when

relative modified unit price was intermediate (i.e., approximately 0.5), an intermediate level of preference between schedules with identical cost-benefit components (open circles), was observed for Pigeon 727 only. Upon replication (open triangles), however, this relation was evident for 3 of 4 pigeons. In Phases 1 and 2, when strong preference for the STD schedule was observed between schedules with different cost-benefit components (gray circles and diamonds), relative modified unit price was less than 0.5.

With respect to preference, the modified unit-price model (Equation 4) appears to hold greater utility than the nominal unit-price model (Equation 1). When the schedule configurations differ, the modified unit-price model predicts the observed preference



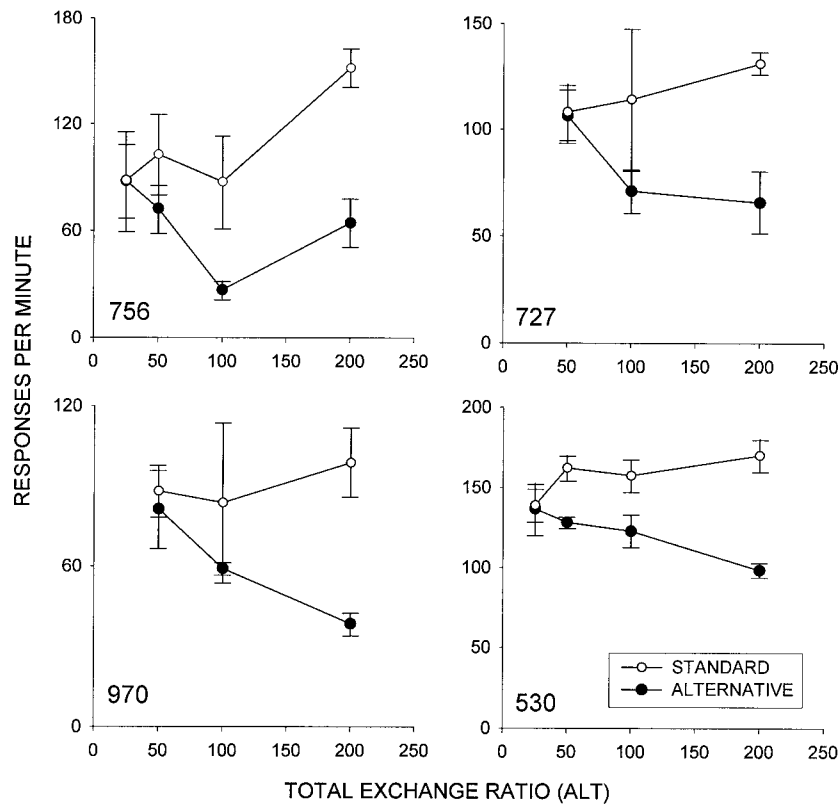


Fig. 4. Mean number of responses per minute under the standard schedule (open circles) and the alternative schedule (filled circles) as a function of the total exchange ratio on the alternative schedule. Error bars indicate the 95% confidence intervals. Note individually scaled y axes.

for the smaller ratio requirements, shorter associated delay, and smaller reinforcer. When schedule configurations were similar, the differences in relative modified unit price were smaller, and Equation 4 predicts the approximate indifference seen under those conditions for 3 of the 4 pigeons. That the modified model predicted the correct direction of preference under the equal unit-price conditions suggests the importance of ratio size, reinforcer immediacy, and reinforcer magnitude.

Figure 4 shows the relation between overall response rates and total exchange ratio for the ALT schedule under unequal unit-price conditions. Total exchange ratio was defined as the overall number of responses required to produce the exchange period (e.g., 100 responses for FR 2 [FR 50]). Mean response rates from the STD (open circles) and ALT (closed circles) components of the multiple-schedule segments of sessions from Phase 1

are shown. The vertical lines indicate 95% confidence intervals. Figure 4 depicts two 4-point functions (Pigeons 756 and 530) and two 3-point functions (Pigeons 727 and 970) because the nominal unit price of 6.25 was arranged with an FR 1 exchange schedule for Pigeons 756 and 530 and with an FR 2 exchange schedule for Pigeons 727 and 970 (see Table 1). For Pigeons 727 and 970, the two conditions in which the total exchange ratio was 50 were averaged.

Response rates on the ALT schedule decreased monotonically with increases in the ALT exchange ratio for 3 of 4 pigeons. For Pigeon 756, response rates also decreased up to FR 100, but increased at the highest value (FR 200). The decreases are consistent with previous reports of FR schedule performance in open economies (e.g., Ferster & Skinner, 1957; Zeiler, 1999), in which increasing FR size produces a monotonic decrement in response rates. Studies of token-reinforcement

procedures using FR production and exchange schedules have produced similar results (e.g., Foster et al., 2001; Kelleher, 1958).

Response rates under the STD schedule were not related systematically to increases in the ALT exchange ratio. At the highest exchange ratio (200), however, STD response rates exceeded those at the lower exchange ratios, diverging appreciably from the ALT response rates. Since the contingencies associated with the STD schedule remained fixed across conditions, the increase in STD response rates at the highest exchange ratio may reflect behavioral contrast (Reynolds, 1961), defined as changes in the response rates in the unchanging component in the direction opposite to the changes in the reinforcement conditions in an alternative component. Such contrast effects have been reported under multiple schedules with FR components (e.g., Bloomfield, 1967).

The relation between STD and ALT response rates shown in Figure 4 is consistent with the direction of preference shown in Figure 2 (black circles). In all cases where the STD schedule was preferred to the ALT schedule, the STD engendered higher response rates. In the single condition in which the ALT schedule was preferred exclusively (6.25), STD and ALT response rates were nearly equivalent.

Removing the token stimuli produced no consistent effects on preference or on response rates. That responding was similar whether the tokens were present or absent could be due to several factors. First, the salience of the token stimuli may pose problems. Unpublished research from our laboratory suggests that stimulus lamps of larger diameter may control behavior more effectively than the present smaller-diameter lamps. Second, the no-token comparisons were conducted only under schedules that arranged a relatively low total exchange ratio. Our previous research (Foster et al., 2001) found that response rates were more sensitive to schedule variables and schedule-correlated stimuli at larger total exchange ratios (e.g., 200, 400). The restricted range of exchange ratios used (50, 100) may have influenced the results. The token-comparison conditions studied here functioned more as probes than as systematic comparisons of token effects. Research currently underway in our labora-

tory is designed to assess the stimulus functions of the tokens more systematically.

On the whole, these results are generally consistent with other findings on concurrent-ratio performance, including those inspired by unit-price concepts (Bickel & Madden, 1999; Madden et al., 2000). In conditions with equal unit price, the option arranging a smaller response requirement and smaller reinforcer magnitude was preferred over a larger response requirement and larger reinforcer magnitude. This type of preference for the smaller more immediate reinforcer is consistent with larger unit-price conditions studied by Madden et al. and with the modified unit-price model (Equation 4). The results are also consistent with research on self-control, which shows that preference is governed to a greater degree by reinforcer immediacy than by reinforcer amount (Logue, 1988; Rachlin, 1995).

## EXPERIMENT 2

The purpose of Experiment 2 was to examine further choice under conditions of equal unit price. The results of Experiment 1 showed that when the cost and benefit factors of nominally equal unit prices are manipulated, the actual unit prices obtained are not functionally equivalent. Preference was affected by other factors (e.g., handling requirements and/or differential reinforcer delays brought on by different ratio-completion times), such that a modified version of unit price was needed to account for the data. Experiment 2 sought to determine the generality of this formulation across a fuller range of conditions of equal unit price.

### *Subjects and Apparatus*

The subjects and apparatus were the same as in Experiment 1.

### *Procedure*

Experimental procedures were the same as in Experiment 1, except that different token schedules were arranged. In Phase 1, the STD schedule arranged a unit price of 12.5; the schedule configuration was FR 2 (FR 50) 4 s food. In Phase 2, the STD schedule arranged a unit price of 25; the schedule configuration was FR 4 (FR 50) 2 s food.

Within each phase, choice was examined

Table 2

The sequence of conditions, number of sessions per condition, and mean number of total choices per session for the final five sessions of each condition (in parentheses) in Experiment 2.

Unit price <sup>a</sup>	Alternative schedules	Unit price	Pigeon			
			756	727	970	530
Phase 1: Standard schedule <sup>b</sup> FR 2 (FR 50) 4 s food, unit price 12.5						
E	FR 2 (FR 25) 2 s food	12.5	15 (16)	15 (15.4)	15 (16)	15 (16)
E	FR 4 (FR 25) 2 s food	12.5	27 (7)	42 (7)	15 (7)	17 (7)
E	FR 4 (FR 50) 4 s food	12.5	17 (5)	16 (5)	17 (5)	19 (5)
E	FR 4 (FR 25) 2 s food	12.5	15 (7)	23 (7)	21 (7)	15 (7)
Phase 2: Standard schedule FR 4 (FR 50) 2 s food, unit price 25						
E	FR 2 (FR 50) 2 s food	25	32 (15.6)	15 (16)	20 (15.2)	17 (15.6)
E	FR 2 (FR 100) 4 s food	25	43 (7)	37 (7)	36 (7)	18 (7)
E	FR 4 (FR 100) 4 s food	25	18 (5)	15 (5)	16 (5)	16 (5)
E	FR 2 (FR 100) 4 s food	25 <sup>c</sup>		35 (7)	21 (7)	30 (7)

<sup>a</sup> E = equal.

<sup>b</sup> In this notation, the token exchange schedule precedes the token production schedule.

<sup>c</sup> This replication was not conducted with Pigeon 756.

across three conditions that arranged equal unit prices, but varied the cost and benefit components of the ratio. Across these conditions, the response requirement on the ALT schedules was either smaller than (Condition 1), equal to (Condition 2), or larger than (Condition 3) that of the STD schedule. Table 2 presents the sequence of conditions and the number of sessions per condition for each pigeon.

#### RESULTS AND DISCUSSION

Figures 5 and 6 show mean choice proportions in Phases 1 and 2 as a function of relative modified unit price of the STD schedule. As in Experiment 1, choice proportions are plotted in relation to the STD schedule. Modified unit price (Equation 4) was calculated in the same manner as in Experiment 1. Absolute number of exchange periods per session is shown in Table 2. Absolute values of exchange delays and modified unit prices are shown in Appendix B.

In each phase, preference shifted from STD to ALT in an orderly fashion as relative modified unit price increased. There was strong preference for the STD schedule when relative modified unit price was low (i.e., less than 0.5; Condition 3). There was strong preference for the ALT schedule when relative modified unit price was high (i.e., greater than 0.5; Condition 1). More intermediate levels of preference were observed when rel-

ative modified unit price approximated 0.5 (Condition 2).

The direction and degree of preferences are consistent with the ordinal predictions of Equation 4. As applied to the present conditions, Equation 4 predicts (a) preference for the ALT schedule under Condition 1, (b) indifference under Condition 2, and (c) preference for the STD schedule under Condition 3. In line with these predictions, strong preferences were obtained for the ALT and the STD under Conditions 1 and 3, respectively, whereas indifference was the modal outcome in Condition 2.

It is important to note that procedural factors may account for variability in the degree of preference seen in Experiments 1 (equal unit-price conditions) and 2 (Condition 2). Figures 3, 5, and 6 show that strong preference (open circles) obtained during initial exposures shifted toward indifference upon replication (open triangles) in most cases. This variability in preference may be influenced by the sequence of conditions coupled with the invariance of the choice-correlated stimuli across conditions. Although forced exposures to contingencies were included, the strong preference during the initial exposure could be due to a carryover effect from the previous condition. The shift toward indifference may be influenced by greater exposure to changing contingencies. By design, the stimuli correlated with STD and ALT sched-

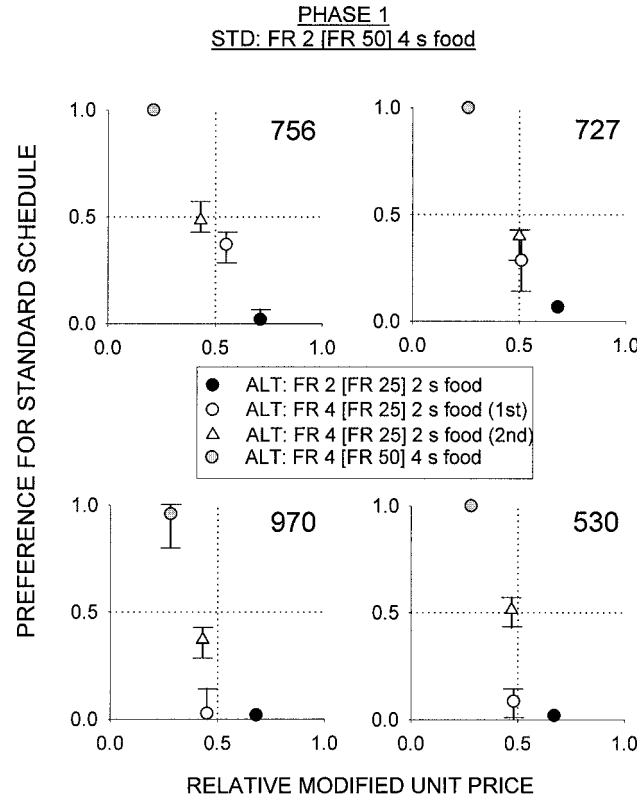


Fig. 5. Mean proportion of choices for the standard schedule as a function of relative modified unit price of the standard schedule (Equation 4). Conditions from Phase 1 of Experiment 2 are shown. Black circles depict conditions in which the standard schedule arranged a larger total response requirement than the alternative schedule. Gray circles depict conditions in which the standard schedule arranged a smaller total response requirement than the alternative schedule. Open symbols depict conditions in which choice alternatives arranged the same total number of responses (circles, first exposure; triangles, replication). Error bars indicate the range of values contributing to the condition mean.

ules remained fixed in order to enhance the discriminability of changes in contingencies. It is possible, however, that such invariance actually made choice contingencies less discriminable over time. The present experiments did not include conditions in which the choice-correlated stimuli were reversed. Future experiments should include such control conditions.

Figure 7 shows mean response rates as a function of total exchange ratio for the ALT schedule in Experiment 2. As in Experiment 1, total exchange ratio was defined as the overall number of responses required to produce the exchange period (e.g., 200 responses for FR 4 [FR 50]). Response rates from the STD (open circles) and ALT (filled circles) components of the multiple-schedule segments of sessions from Phases 1 (left column)

and 2 (right column) are shown. Response rates on the ALT schedule generally decreased as ALT exchange ratio increased in both phases. This finding is consistent with the response-rate decrements seen under the unequal unit-price conditions in Experiment 1 (Figure 4). Systematic decreases in response rates in Experiment 2 are noteworthy, however, because the conditions arranged nominally equal unit prices and therefore an equivalent overall number of responses per reinforcer.

Under the unequal unit-price conditions in Experiment 1, relative differences in response rates under STD and ALT schedules (Figure 4) coincided with preferences (Figure 2). Under the equal unit-price conditions in Experiment 2, the relation between response rates and preference was less consis-

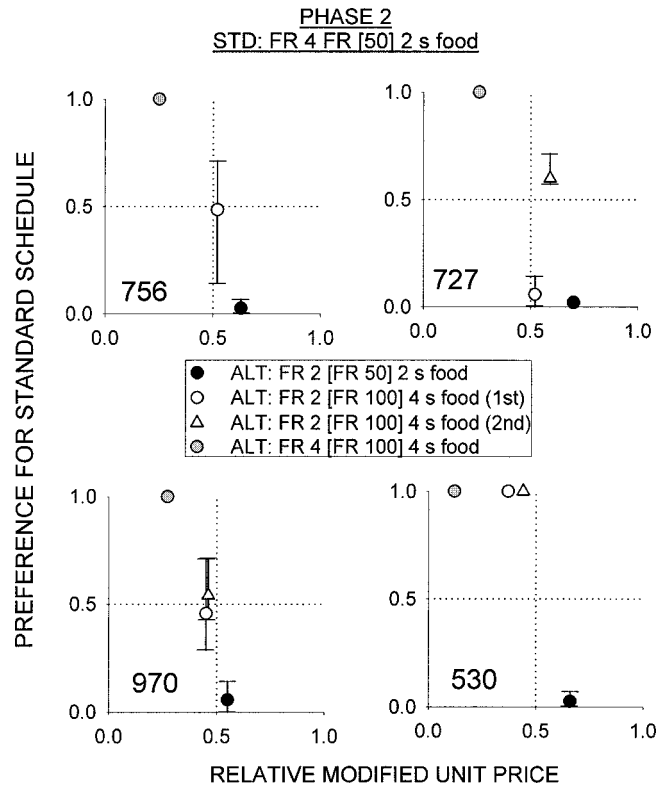


Fig. 6. Mean proportion of choices for the standard schedule as a function of relative modified unit price of the standard schedule (Equation 4). Conditions from Phase 2 of Experiment 2 are shown. Black circles depict conditions in which the standard schedule arranged a larger total response requirement than the alternative schedule. Gray circles depict conditions in which the standard schedule arranged a smaller total response requirement than the alternative schedule. Open symbols depict conditions in which choice alternatives arranged the same total number of responses (circles, first exposure; triangles, replication). Error bars indicate the range of values contributing to the condition mean.

tent. For Phase 1, the relation between STD and ALT response rates shown in Figure 7 (left column) coincided well with the direction of preference shown in Figure 5. In all cases where the STD schedule was preferred to the ALT schedule (gray circles in Figure 5), the STD engendered higher response rates (exchange ratio 200 in Figure 7). In all cases where the ALT schedule was preferred to the STD schedule (black circles in Figure 5), the ALT schedule engendered higher response rates (exchange ratio 50; Figure 7). In the condition in which the modal outcome was intermediate preference, STD and ALT response rates were most similar for 3 of 4 pigeons (exchange ratio 100, Figure 7). For Phase 2, similar relations between response rates and preference held for only 2 of the 4 pigeons (727 and 530).

Response rates under the STD schedule were not related systematically to increases in the ALT exchange ratio. As in Experiment 1, however, STD response rates diverged appreciably from the ALT response rates at the highest exchange ratio. In Phase 1, STD response rates at exchange ratio 200 exceeded those at lower exchange ratios for 2 of 4 pigeons (727 and 530). Response rates for Pigeon 756 exceeded those of the exchange ratio 100 condition. In Phase 2, a similar relation held for Pigeons 727 and 530 at exchange ratio 400. As in Experiment 1, such increases in STD response rates at the highest exchange ratios might be an instance of behavioral contrast, as the reinforcer rate in the ALT component decreased appreciably in this condition.

Figure 8 shows response rates plotted



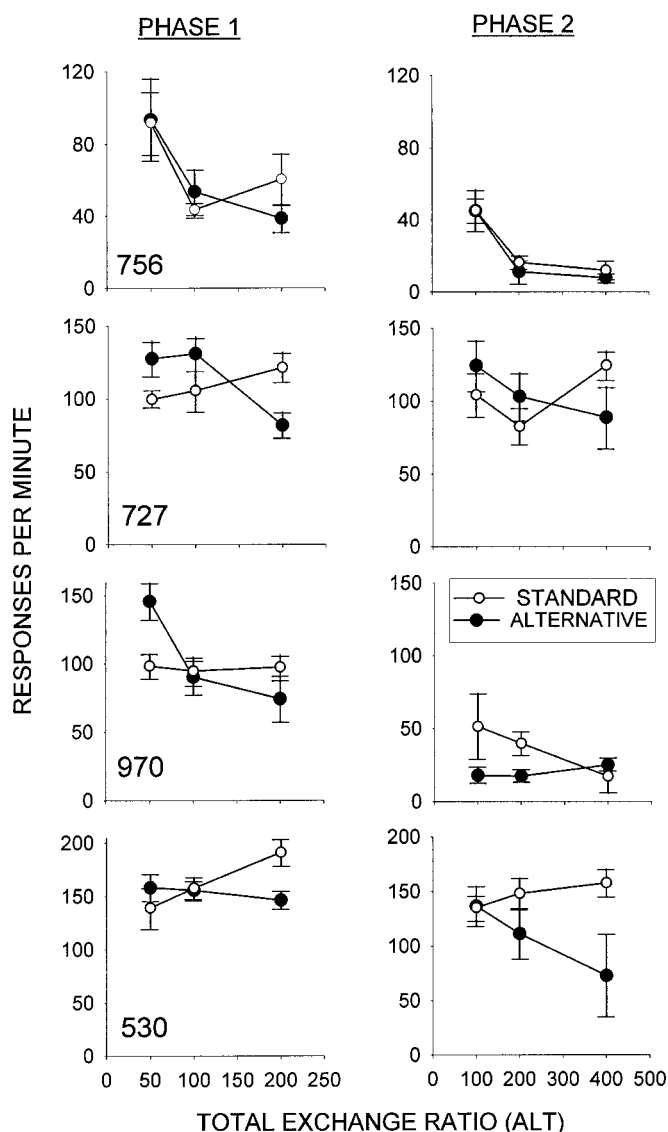


Fig. 7. Mean number of responses per minute under the standard schedule (open circles) and the alternative schedule (filled circles) as a function of the total exchange ratio on the alternative schedule. Conditions from both Phase 1 (left panel) and Phase 2 (right panel) are shown. Error bars indicate the 95% confidence intervals. Note individually scaled y axes.

across successive token-production segments in the multiple schedule for conditions in Experiment 2. To conserve space, data from the STD and ALT schedules were averaged across conditions. Response rates are plotted with respect to FR 2 (open circles) and FR 4 (closed circles) exchange schedules. Under both exchange schedules, responding was characterized by a bi-valued pattern for all pigeons: Low initial-segment rates gave way to

higher rates in later segments. Initial-segment rates were consistently higher under FR 2 exchange schedules than under FR 4 exchange schedules. Separate analyses (not shown here) showed that the bi-valued response pattern and associated exchange schedule effects were evident across all schedule configurations in both phases.

Most of the differences in absolute response rates shown in Figure 7 were due to

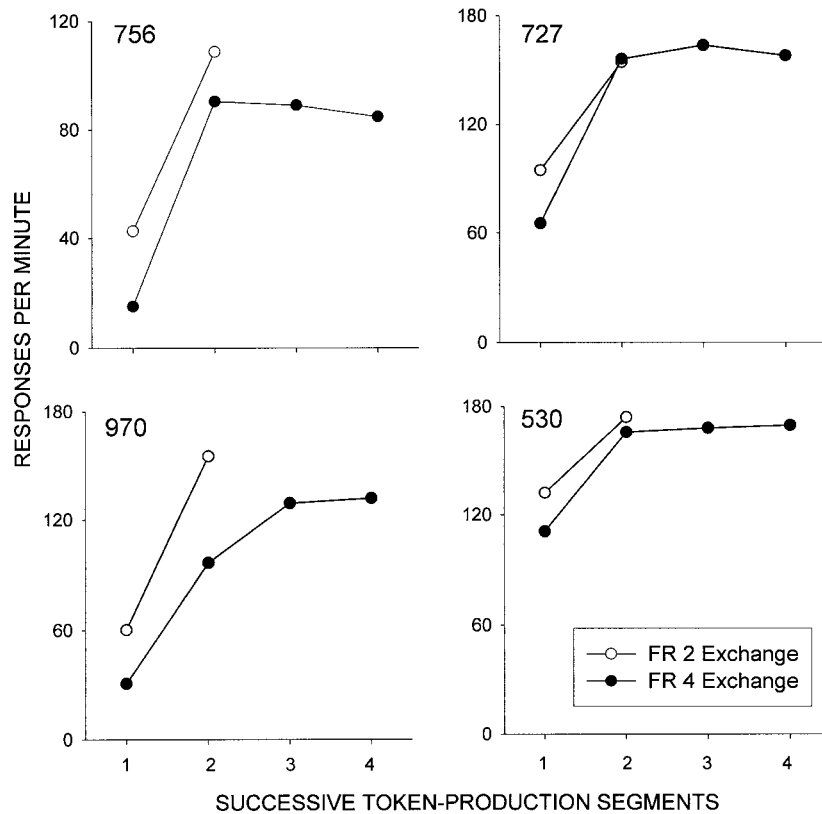


Fig. 8. Mean number of responses per minute across successive token-production segments averaged across both standard- and alternative-schedule configurations in Experiment 2.

differences in rates in the initial segments of the token-production schedule. Separate analyses (not shown here) revealed that such differences were also apparent in local initial-segment response rates (i.e., with preratio pausing subtracted out). These within-ratio patterns resembled those obtained in previous studies of schedule performance under second-order token reinforcement schedules with ratio production and exchange schedules (e.g., Foster et al., 2001; Kelleher, 1958; Webbe & Malagodi, 1978; see review by Golub, 1977).

Our treatment of the response patterning under Experiment 2 is necessarily abbreviated. We present Figure 8 to make contact (albeit qualitative) with previous token-reinforcement research, and not to make precise quantitative statements about particular schedule configurations and conditions. Interested readers should consult Foster et al. (2001) for a more extensive discussion of response patterning effects.

## GENERAL DISCUSSION

When choice between unequal unit prices was arranged, exclusive preference for the lower-priced option was seen. When choice between equal unit prices was arranged, the direction and degree of preference varied depending upon the size of the ratio requirements. When ratio requirements differed, exclusive preference was found for the option with the lower ratio. When ratio requirements were equal, preferences were nearer indifference.

The main findings of the present experiments are consistent with previous research on choice under concurrent ratio schedules, including recent studies of choice under different conditions of unit price (Bickel & Madden, 1999; Madden et al., 2000). The present results differed from those reported by Madden et al., however, in the lower unit-priced conditions. Unlike Madden et al.'s humans, who preferred the larger-magnitude reinforc-

er at relatively smaller unit prices, our pigeons preferred the schedule with the smallest ratio (hence, shorter delay to food) whenever the ratio of responses per exchange period was unequal.

The factors responsible for the difference between the present results and those of Madden et al. (2000) are not immediately apparent. There were several procedural differences between the studies, most notably species (pigeons vs. humans) and reinforcer type (food vs. cigarettes), which may be responsible. Another difference concerned the type of contact with the schedules. The present study provided direct, extended exposure to the schedules, both within and across sessions. In the Madden et al. study, by contrast, exposure to the contingencies was brief (one session per condition) and supplemented with verbal descriptions of the contingencies. Future research will be needed to determine the sources of the different patterns of results and the generality of such results across species and reinforcers.

Despite these differences, both the present results and those of Madden et al. (2000) were in general accord with the predictions of Equation 4, a modified version of the unit-price model that incorporates handling and reinforcement delay as additional cost factors. These additional cost factors effectively transform nominally equal unit prices to unequal unit prices, permitting ordinal predictions of preference. The model accurately predicted the observed preferences for the alternative with the lower unit price. Because ratio size and reinforcer delay (ratio-completion time) covaried, however, it is not possible to isolate their separate effects as cost factors in the modified unit-price model (the terms in the numerator of Equation 4).

It is possible, however, to examine the extent to which obtained ratio-completion times alone could account for the present results. We analyzed the relation between relative delay to the exchange period (timed from first to last response in the ratio) and relative modified unit price under conditions in Experiment 2. As before, relative measures were calculated in relation to the STD schedule. Absolute measures of delay and modified unit price are shown in Appendix B. For all pigeons, the relative obtained delay to the exchange period was correlated strongly with

relative modified unit price. All functions were described well by a straight line (mean  $r^2 = 98.5$ ). This strong, direct relation between obtained delays and modified unit price shows that the delay parameter ( $D$ ) accounted for nearly all of the variance in the modified unit price calculation (Equation 4). Relative to  $D$ , the other parameters ( $H$ ,  $A$ ) contributed little to the obtained preferences. This outcome has important implications for our previous preference analyses (Figures 3, 5, and 6). Extending this relation to our previous analyses, it becomes evident that the  $D$  parameter in the model characterizes well the observed choice patterns, and thus offers a simpler and more powerful account of preference in Experiment 2.

One problem with such an explanation, however, is that obtained delay on ratio schedules is an *indirect variable*, that is, a variable imposed but not formally specified by the schedule (Zeiler, 1977). Future research should seek to convert such indirect variables to *direct variables*, that is, variables formally prescribed by the schedule. One way to accomplish this is to yoke ratio-completion times to interval schedules, as has been done effectively in demand-curve research (Bauman, 1991; Tsunematsu, 2000). Extending this analytic strategy to choice procedures will permit an assessment of the relative contributions of delay and response requirements as cost factors in unit-price models.

That handling costs (defined here as the exchange responses) contributed little to the overall costs is perhaps not surprising, as they added at most four responses (one for each food delivery scheduled during an exchange period) to a ratio of 100 or more. It is perhaps more surprising how little choices were affected by reinforcer magnitude, one of the key constituents of unit-price models.

In its simplest form, the unit-price model assumes unit increases in reinforcer magnitude yield unit increases in utility, or reinforcer value. In other words, a reinforcer of size  $n$  is assumed to be one half the value of a reinforcer of size  $2n$ . This may be a reasonable simplifying assumption, but it runs counter to a range of findings showing nonlinear discounting of reinforcer value as a function of reinforcer magnitude (Killeen, 1985, 1995). Such findings embody the economic notion of diminishing marginal utility, where-

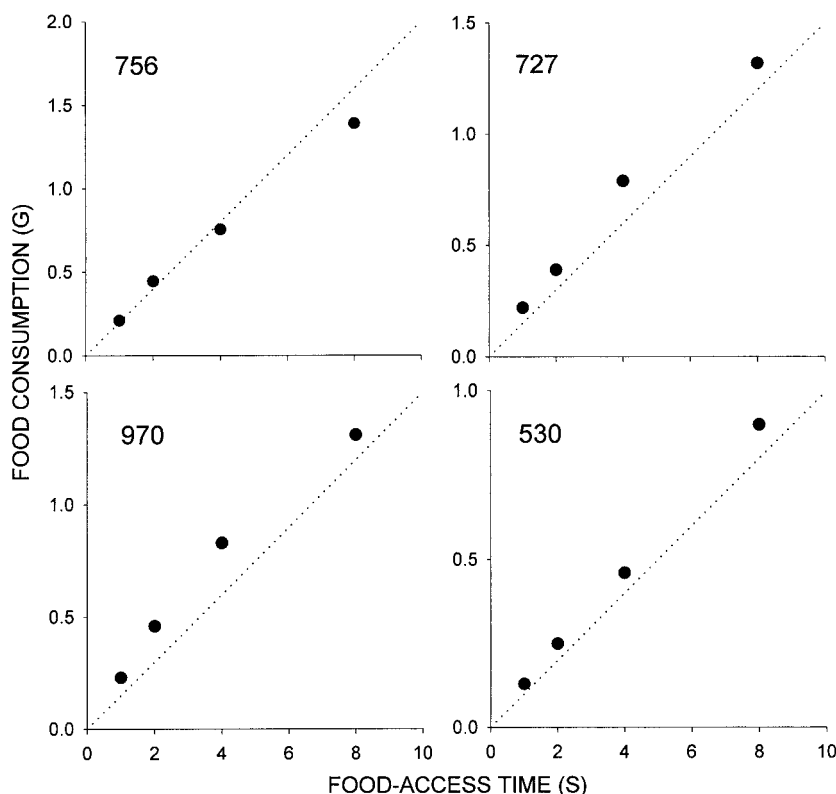


Fig. 9. Mean amount of food consumed (g) as a function of food-hopper access time. Note individually scaled y axes.

by increases in reinforcer magnitude produce less than proportional increments in reinforcer value (Rachlin, 1992).

This has important implications for the present results, for if relatively large reinforcers yield less than proportional increments in reinforcer value (e.g., 4-s access to food is less than twice the value of 2-s access to food), then a key simplifying assumption of the unit-price model is violated. Such nonlinear discounting of reinforcer value would also provide an alternative account of the observed preferences for the relatively smaller ratio/reinforcer alternative over the relatively larger ratio/reinforcer alternative.

We therefore examined our results for evidence of nonlinearity in the function relating value to reinforcer magnitude. Because reinforcer magnitude was specified here as food-access time, it was first necessary to assess the relation between programmed and obtained food amounts. To eliminate the latency between food presentation and food access, the hopper cycle was timed from the

point of head entry into the food aperture. This method ensures good correspondence between programmed and obtained hopper durations, but it does not necessarily ensure equal consumption across the reinforcer cycle, as required by the unit-price formulation. It is possible, for example, that consumption rate changes across the hopper cycle, perhaps due to mechanical characteristics of the food hopper (cf. Epstein, 1981, 1985).

To assess the relation between amount of food arranged and amount of food actually consumed in our study, we measured consumption at different hopper-cycle durations. Following Experiment 2, each of the 4 pigeons was exposed to simple FR 25 schedules of food delivery for 40 daily sessions, each consisting of 20 hopper cycles. The duration of the hopper cycles was varied systematically across five-session blocks (1, 2, 4, and 8 s). Hopper duration was first varied in an ascending, then in a descending, sequence. Figure 9 shows the mean number of grams consumed per food delivery as a function of the

food hopper duration. For all pigeons, the amount of grain consumed increased as a direct function of hopper duration. Although there were hints of downward concavity at the upper end, the function is sufficiently linear across the range of the function containing the hopper-access times used in the present study (1 to 4 s). These results are generally consistent with those of Epstein (1985), who reported a roughly linear relation between programmed and obtained amount of food across an even larger range of hopper-duration values.

If value is indeed a nonlinear, negatively accelerated function of reinforcer magnitude, as several studies have shown, it is apparently not due to changes in consumption rate within a reinforcer cycle, which our results showed were roughly constant. Still, it is possible that the function relating reinforcer value to reinforcer magnitude is nonlinear in spite of constant consumption rates. For example, Killeen (1995) suggested that the nonlinearity is due not to changes in consumption within a cycle, but to delay-based discounting:

The second, third, and  $n$ th instants of consumption are not contiguous with the response that brought them about; they are separated from it by  $n - 1$  prior instants of consumption that block their effectiveness. The last instants of a long-duration reward constitute a delayed reward. (p. 417)

If this is the case, then one would expect two smaller reinforcers of size  $n$ , occurring in close succession but each produced by a response, to exceed the value of one large reinforcer,  $2n$ , owing to greater response-reinforcer contiguity of the former. Because reinforcers in the present study were arranged in succession within an exchange period, and each was contiguous with the exchange response that produced it, some conditions in the present study arrange the kind of choices that may be useful in evaluating such delay-based discounting of reinforcer magnitude. In particular, Condition 2 in both phases of Experiment 2 arranged similar overall ratio requirements (total number of production responses to the first reinforcer in the exchange period) and similar overall reinforcer magnitudes (total amount of food per exchange period), but different se-

quences of reinforcers within an exchange period between their respective STD and ALT schedules.

Across the 15 cases in which such choices were arranged, the modal outcome was approximate indifference (see Figures 5 and 6, open symbols), suggesting that the particular configuration of reinforcer size and amount did not much matter. In other words, the negligible contribution of reinforcer magnitude to the present choice patterns was not due to the declining value of a reinforcer within a hopper cycle. Such results should be viewed cautiously, however, as they are based on a restricted range in both reinforcer number and size. Nevertheless, they illustrate a potentially useful method for varying the size and number of reinforcers independently of ratio requirements and reinforcer delays. A fuller examination of such procedures across a wider parametric range promises to provide an important source of data on the characteristics of the utility function relating reinforcer value to reinforcer amount and number. This would have clear implications for general models of choice, including, but not limited to, unit-price models.

Response rates under the multiple schedule were generally in accord with the choice proportions under the concurrent schedules, insofar as the direction of effects is concerned. In addition, multiple-schedule response rates varied with total exchange ratio in a manner broadly consistent with prior findings on response output on simple schedules. Together, these findings suggest a possible connection between response rate and preference as they relate to the unit-price formulation. Such connections must be regarded as tentative at present, as the current multiple-schedule format was used chiefly as a means for ensuring contact with the schedule components prevailing during the subsequent concurrent-schedule segments of the session. For this reason, these data were not used as a basis for assessing stability and therefore cannot be seen as necessarily representative of steady-state performance. Moreover, the present multiple-schedule procedures placed constraints on schedule availability and consumption, necessitating rate measures rather than the more typical frequency measures (i.e., total response output). More research is needed to clarify the rela-



tion between response rate and choice proportions, including more extensive analyses of local response patterning underlying the more global measures of response output and preference. Such schedule dynamics will need to be addressed by the next generation of unit-price models, which have focused mainly on global measures of response output. Broader and more behaviorally sophisticated unit-price concepts will be among the potential benefits of such research.

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#### APPENDIX A

Mean delay to the exchange period and mean modified unit price for the final five sessions of the equal unit price conditions in Experiment 1.

Pigeon	Alternative schedules	Delay (s)		Modified unit price	
		STD	ALT	STD	ALT
Phase 1: Standard schedule FR 2 (FR 25) 2 s food, unit price 12.5					
756	FR 2 (FR 25) 2 s food <sup>a</sup>	15.16	25.58	218.16	358.83
	FR 2 (FR 25) 2 s food <sup>b</sup>	18.80	41.03	267.30	567.40
	FR 4 (FR 50) 4 s food	16.01	153.91	229.63	2,091.28
727	FR 2 (FR 25) 2 s food	20.49	18.03	290.12	256.91
	FR 2 (FR 25) 2 s food	22.05	20.07	311.17	284.44
	FR 4 (FR 50) 4 s food	18.64	95.36	265.14	1,300.86
970	FR 2 (FR 25) 2 s food	34.92	21.93	484.92	309.56
	FR 2 (FR 25) 2 s food	31.95	20.38	444.82	288.63
	FR 4 (FR 50) 4 s food	19.14	136.49	271.89	1,856.12
530	FR 2 (FR 25) 2 s food	15.39	17.92	221.27	255.42
	FR 2 (FR 25) 2 s food	16.29	17.54	233.41	250.29
	FR 4 (FR 50) 4 s food	14.62	71.26	210.87	975.51
Phase 2: Standard schedule FR 2 (FR 50) 2 s food, unit price 25					
756	FR 2 (FR 100) 4 s food	45.18	172.36	1,200.68	4,420.68
727	FR 2 (FR 100) 4 s food	40.56	108.09	1,080.56	2,781.79
970	FR 2 (FR 100) 4 s food	42.51	162.95	1,131.26	4,180.72
530	FR 2 (FR 100) 4 s food	33.23	78.67	889.98	2,031.58

<sup>a</sup> First exposure.

<sup>b</sup> Replication.

## APPENDIX B

Mean delay to the exchange period and mean modified unit price for the final five sessions of conditions in Experiment 2.

Pigeon	Alternative schedules	Delay (s)		Modified unit price	
		STD	ALT	STD	ALT
Phase 1: Standard schedule FR 2 (FR 50) 4 s food, unit price 12.5					
756	FR 2 (FR 25) 2 s food	53.34	20.32	706.42	287.82
	FR 4 (FR 25) 2 s food <sup>a</sup>	72.23	52.30	951.99	772.85
	FR 4 (FR 25) 2 s food <sup>b</sup>	62.93	72.76	831.09	1,069.52
	FR 4 (FR 50) 4 s food	59.40	207.49	785.20	2,814.61
727	FR 2 (FR 25) 2 s food	43.07	18.79	572.91	267.16
	FR 4 (FR 25) 2 s food	44.02	36.65	585.26	545.92
	FR 4 (FR 25) 2 s food	41.15	35.33	547.95	526.78
	FR 4 (FR 50) 4 s food	41.00	110.90	546.00	1,510.65
970	FR 2 (FR 25) 2 food	40.99	18.00	545.87	256.50
	FR 4 (FR 25) 2 s food	47.52	52.04	630.76	769.08
	FR 4 (FR 25) 2 s food	45.19	52.51	600.47	775.89
	FR 4 (FR 50) 4 s food	42.04	105.01	559.52	1,431.13
530	FR 2 (FR 25) 2 s food	35.64	15.80	476.32	226.80
	FR 4 (FR 25) 2 s food	33.64	32.36	450.32	483.72
	FR 4 (FR 25) 2 s food	33.60	33.10	449.80	494.45
	FR 4 (FR 50) 4 s food	28.24	70.32	380.12	962.82
Phase 2: Standard schedule FR 4 (FR 50) 2 s food, unit price 25					
756	FR 2 (FR 50) 2 s food	160.58	93.93	4,362.66	2,468.18
	FR 2 (FR 100) 4 s food	413.19	395.59	11,183.13	10,113.05
	FR 4 (FR 100) 4 s food	333.17	1,029.08	9,022.59	26,782.08
727	FR 2 (FR 50) 2 s food	91.74	39.23	2,503.98	1,045.98
	FR 2 (FR 100) 4 s food <sup>a</sup>	86.70	82.92	2,367.90	2,139.96
	FR 2 (FR 100) 4 s food <sup>b</sup>	152.97	108.36	4,157.19	2,788.70
	FR 4 (FR 100) 4 s food	85.52	239.64	2,255.01	6,256.71
970	FR 2 (FR 50) 2 s food	102.70	84.31	2,799.90	2,218.06
	FR 2 (FR 100) 4 s food	167.99	211.03	4,562.73	5,406.76
	FR 2 (FR 100) 4 s food	128.94	155.87	3,508.38	4,000.18
	FR 4 (FR 100) 4 s food	172.99	483.71	4,697.73	12,602.46
530	FR 2 (FR 50) 2 s food	74.35	39.13	2,034.45	1,043.38
	FR 2 (FR 100) 4 s food	76.72	134.70	2,098.44	3,460.35
	FR 2 (FR 100) 4 s food	69.89	93.35	1,914.03	2,405.92
	FR 4 (FR 100) 4 s food	71.01	507.29	1,944.27	13,215.54

<sup>a</sup> First exposure.

<sup>b</sup> Replication.